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IRRIGATION AND RELATED CULTURAL PRACTICES WITH COTTON IN THE SALT RIVER VALLEY OF ARIZONA

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INTRODUCTION

Cotton production in the Salt River Valley of Arizona is a relatively new agricultural enterprise, for it was not until 1917 that the acreage was of sufficient magnitude to justify giving it serious consideration when compared with the acreages devoted to other crops. For reasons not always apparent, in certain parts of the valley yields have not been maintained, and under more unfavorable conditions there has been a definite tendency for them to be materially less than those formerly harvested.

For the first few years after the introduction of cotton into the Salt River Valley the conditions were particularly favorable for the harvesting of satisfactory yields. A large part of the acreage planted to cotton had previously been in alfalfa for many years, and pasturing had been extensively practiced. Not infrequently yields were harvested amounting to a bale or more to the acre of the American Egyptian or Pima variety, which stimulated interest in cotton as a substitute for other crops. The high prices paid for the product during the World War and at subsequent intervals also stimulated increased acreages of cotton in the valley. Because of these attractive yields and prices the importance of selecting land adapted

to cotton production and the adoption of sound cultural and irrigation practices were often minimized. The recent decline in the value of the product has made it increasingly evident that a new and higher standard as to yield must be set materially in excess of that formerly in effect if cotton production is to remain a profitable farm enterprise.

Definite progress has been made along certain lines toward placing the industry on a better basis. Varieties that are superior in lint qualities and in adaptability to the local conditions have been made available, and large supplies of pure planting seed have been provided. The importance of planting only seed free from varietal contamination is generally recognized, and this practice is usually followed. This is evidenced by the establishment of single-variety communities or by planting only seed from fields that have been planted with pure seed and are sufficiently isolated from other varieties to prevent contamination. Marketing practices have been improved; much of the cotton has been handled cooperatively, carefully, and competently graded, and sold in even running lots to the mutual advantage of producer and consumer. Organizations are maintained to furnish adequate labor for picking the crop, and progress is being made toward better ginning. All these factors have been helpful in stabilizing the industry, but other problems, some of them highly important, remain to be solved before the future prosperity of the industry is assured. •

Efforts expended in improvement of seed stocks and maintaining their purity, and in adopting better marketing facilities, will be largely nullified unless yields are maintained and the quality of the lint kept sufficiently high to meet the demands of the trade. A better knowledge of the fundamentals of sound cultural and irrigation practices and their adoption will increase the yields and raise the quality of the Pima variety and should encourage an expansion of the acreage devoted to this superior type, to the advantage of the individual farmer as well as of the community as a whole. (Fig. 1.)

In Maricopa County (11)¹ the cotton acreage reached a maximum of approximately 180,000 acres in 1920 and was close to 118,000 acres in 1930, this latter figure being not far from one-third of the total area in the valley at present irrigated. As additional land is brought under irrigation, it is probable that there will be an increase in the cotton acreage, particularly if a superior quality of lint is produced and the yields become more nearly equal to those harvested by the better farmers during the earlier years.

Prior to 1922 the variety planted was almost exclusively Pima or American Egyptian. Since 1921 varying proportions of different varieties of upland, with Acala predominating, have been planted. This change from Pima to upland was in part due to a lowering of the price differential. Another factor was the marked tendency to a decline in the yields of Pima cotton, particularly on certain soil types, which caused many growers to believe that better yields and larger returns could be expected from certain upland varieties. Quite generally these unsatisfactory yields from Pima cotton were obtained from the heavier soils, where it was difficult to secure

¹ Italic numbers in parentheses refer to Literature Cited, p. 31.

proper water penetration, and on farms where the cropping system has not maintained the productivity of the soil. Such areas, as well as land recently reclaimed from desert, are now planted to other crops or devoted to the production of upland cotton. However, experienced growers have not realized the advantages expected from this substitution, and the change proved to be largely an evasion rather than a solution of the problems of efficient cotton production under irrigation. It has been found that intelligent application of water, together with sound cultural practices, is essential in order to obtain large yields of good lint from any variety grown. The cotton industry will be greatly stabilized, to the advantage of the individual and the community, when there is a more general appre-



FIGURE 1.—Pima cotton grown under well-conducted irrigation practices. Salt River Valley, Ariz.

ciation that irrigation and cultural problems can not be solved by changing from one variety of cotton to another.

CLIMATIC CONDITIONS

The climate of that section of southern Arizona represented by the Salt River Valley is characterized by light rainfall, relatively high summer temperatures, low humidity, and mild winters. Meteorological records kept by the United States Weather Bureau at Phoenix since 1895 show that the mean annual precipitation for the 34-year period from 1895 to 1928, inclusive, has been 7.86 inches. Since this is distributed over 12 months and much of it in the form of light showers, it has little importance in crop production.

The average date of the last spring frost is given as February 10 and that of the first frost in the fall as December 4, with a frost-free season of 296 days. This is somewhat longer than the actual growing season for much of the cultivated land.

Table 1 gives the mean maximum, mean minimum, and the mean monthly temperatures for the period 1895 to 1928.

TABLE 1.—Mean maximum, mean minimum, and mean temperatures ($^{\circ}$ F.) at Phoenix, Ariz., 1895 to 1928

[As reported by the U. S. Weather Bureau]

Items of comparison	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Mean maximum...	64.9	69.0	74.0	81.7	90.0	100.8	102.7	100.8	96.7	85.8	74.5	64.7	83.8
Mean minimum...	39.0	43.0	46.7	52.2	59.5	68.6	76.3	75.2	68.3	55.5	45.2	38.5	55.7
Mean.....	51.9	55.7	58.6	67.0	74.9	84.7	89.5	88.0	82.5	70.6	59.8	51.6	69.6

The mean maximum temperatures for June, July, and August are all above 100° F., and with the low humidity that characterizes the climate of Arizona the potential evaporation naturally is high.

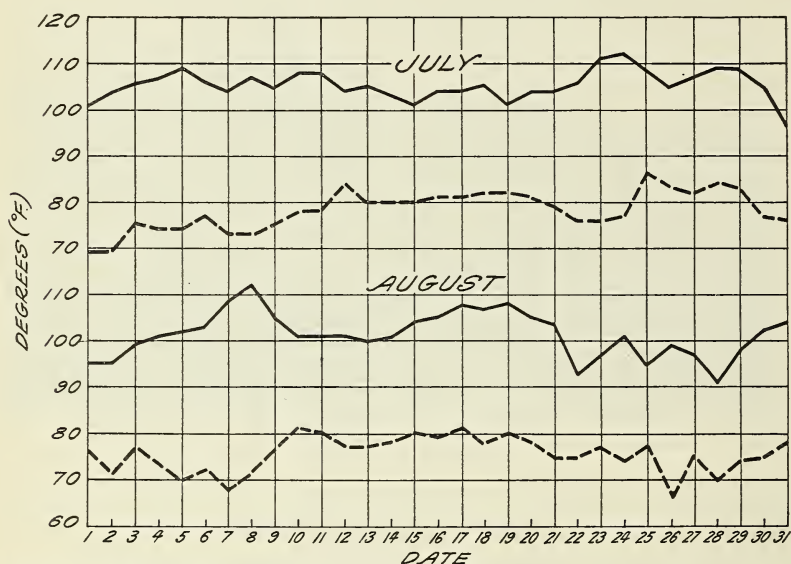


FIGURE 2.—Maximum and minimum daily temperatures for July and August, 1928, showing fluctuations (solid line daily maximums, dotted line daily minimums)

The mean minimum temperatures for July and August are also high. These two months constitute the period when the plants should put on the major part of their crop, but it often happens that abrupt changes from moderate to high temperatures occur at this season and materially increase the transpiration strain and the rate of shedding. These temperature fluctuations are illustrated graphically in Figure 2, which gives the maximum and minimum daily temperatures for July and August, 1928.

During the early part of July, 1928, the maximum temperatures were fairly consistent, but from a temperature of 101° F. on the 19th there was a rapid increase to 112° on the 24th. Again, during the period beginning July 31 and extending to August 3, inclusive, maxima below 100° were recorded, while between the latter date and August 8 there was an increase of 13° , or an extreme range between August 2 and 8 of 17° . In the case of minimum temperatures,

abrupt changes from moderate temperatures such as those on August 5, 6, and 7 to that occurring on the 10th and following days often have been observed to exert the same effect in intensifying stress conditions in cotton as do similar changes in maximum temperatures.

Even when temperatures are uniformly high during a long period, the adverse effects on the behavior of cotton are very apparent if soil-moisture conditions are unfavorable as a result of the soil becoming too dry, or of inadequate penetration of water, or of too high a concentration of salt in the soil solution. With occurrence of rather wide fluctuations such as those indicated in Figure 2, injury to the crop is definitely more pronounced, and it is only under the most favorable conditions of soil moisture that the crop is able to pass through such periods without undergoing serious injury such as the shedding of buds or young bolls.

PLANT REACTIONS UNDER UNFAVORABLE GROWTH CONDITIONS

In addition to restricting the growth, reactions of the plant under unfavorable conditions of growth are manifested largely in four ways, namely, by shedding of the squares or bolls, by reduction in the size of bolls, by intensification of the disorder commonly known as "crazy top," and by decline in the length and quality of the lint.

When temperatures are moderate, shedding of the squares or bolls is often not noticeable, but as temperatures become materially higher, losses become more severe unless growth conditions are favorable. With abrupt change to materially higher temperatures the losses are even more apparent. It is well recognized that shedding usually is more severe on the heavier soil types, particularly on those that are impervious to water. The losses on such soil have at times been so great that certain fields hardly justify picking (fig. 3), while other fields not far distant produced very satisfactory yields (fig. 4).

Reduction in the size of bolls is an important factor in reducing cotton yields. A comparison of the number of seeds per boll from cotton subjected to severe stress as compared with that from normal plants has shown a marked reduction in the number of seeds and a corresponding loss in weight, often amounting to as much as one-third to one-half. The reduction in the size of bolls has been most noticeable where the conditions of growth have been definitely unfavorable, such as is the case where the crazy-top disorder occurs. (Fig. 5.) Investigations have also disclosed a correlation between the size of bolls and the amount of shedding under stress conditions; the more severe the shedding, the more adversely are the bolls affected.

The distinctive features of the disorder commonly known as crazy top (1) are abnormal vegetative growth and sterility. The latter varies in degree according to the severity of the plant infection. Crazy top was first observed about 1919, but was not recognized as of much importance until 1922, when it was found to be widely distributed throughout the Salt River Valley and was recognized by a number of growers. Where crazy top is present, the size of the bolls is often affected more adversely than where plants have suffered heavy shedding without manifesting definite symptoms of the disease. Observations made over a long period indicate that



FIGURE 3.—Acala cotton plant showing definite injury from stress conditions. Note few open bolls at base of plant, which were formed during the cooler spring weather; almost complete sterility, representing midseason growth when temperatures were highest, at the middle of the plant; and a few bolls at the top, which were set after the summer temperatures had moderated. The soil is of fine texture, and adequate penetration of irrigation water is difficult to obtain on such soils. Compare with Figure 4. (Photographed by H. F. Loomis)

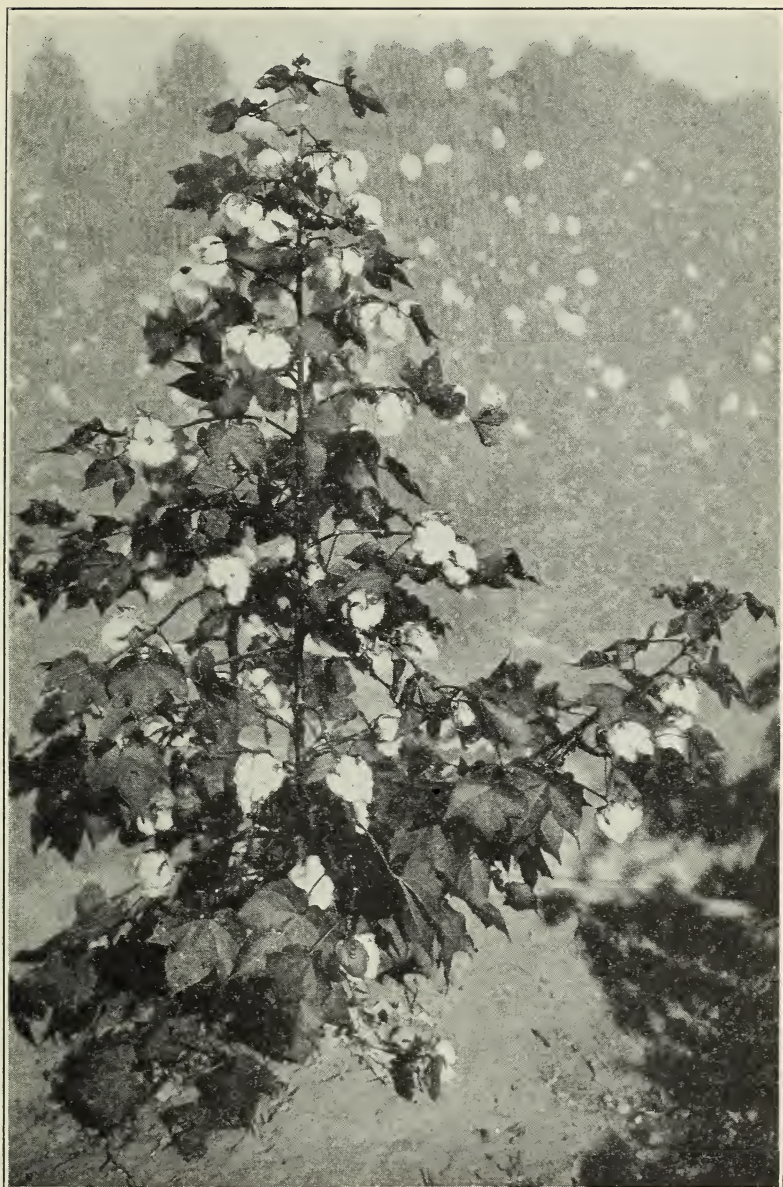


FIGURE 4.—Normal Acala cotton plant grown on soil which takes irrigation water readily. Note fruit evenly distributed from the bottom to the top of the plant. Compare with Figure 3. (Photographed by R. L. Taylor)

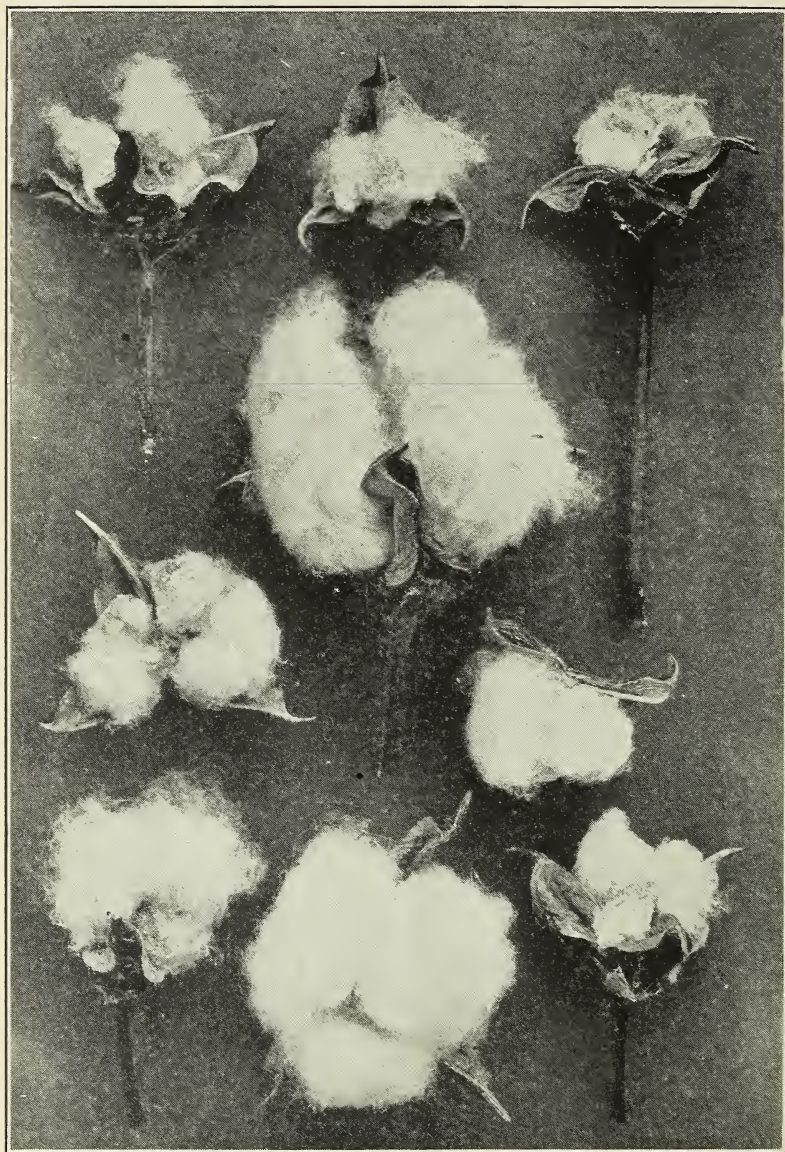


FIGURE 5.—Pima cotton bolls, normal and affected with crazy top. The two large bolls in the center are from normal plants, and the others are from deranged plants produced under stress conditions. Such bolls are not only much smaller but the quality of the lint is adversely affected. (Photographed by H. F. Loomis)

excessive shedding may be a preliminary expression of the disorder, and that other abnormalities of plant growth may be apparent only in advanced stages of crazy top.

Crazy-top injury and stress conditions are correlated, as indicated by the seasonal occurrence of the disease and the character of the soil where it is most often found. The disease is rarely apparent in the spring when temperatures are moderate, but as they become materially higher and the plants grow and increase their rate of transpiration, losses become noticeable. The marked tendency of the plants to recover from the disorder during the cooler fall months indicates that while water stress may not be the sole cause of the disorder, it greatly aggravates the injury. Crazy top has been most prevalent on heavy-soil types where adequate water penetration has been difficult to obtain.

Buyers and consumers frequently complain that the quality and length of fiber of cotton grown under irrigation are not now as satisfactory as in cotton produced during earlier years. Although the justification of these complaints has often been questioned, it has been apparent that as production problems have become more acute the complaints have become more common. It is true of crops in general that where growth conditions are such that yields are materially reduced, usually the quality of the product is not maintained at a high standard. There is no reason to suppose that cotton is an exception to this rule. Examination of lint from fields where soil or water conditions have been so unfavorable that the yields have been materially depressed reveals a quality of lint materially lower than that from fields where good yields have been obtained.

It is probable that these unfavorable plant reactions can not be attributed to any one cause. The fact that they become definitely more pronounced as the plants become larger and the temperatures higher, with a corresponding increase in transpiration losses, in a large measure justifies the belief that the amount and availability of the moisture supply in the soil is a more important factor than is now recognized. If the root zone of the plant is too limited, if the soil is allowed to become too dry, or if the character of the water is such that it is only partially available to supply the needs of the plants, it appears inevitable that normal plant development can not be expected.

ACCUMULATION OF SALTS FROM CONTINUED IRRIGATION

Where cotton fields are sparingly irrigated year after year and where the water applied merely replenishes the supply in the root zone, there is likely to be an accumulation of harmful quantities of alkali salts, and this is inevitable if the irrigation water contains such salts in considerable quantities. To appreciate this condition it should be understood that irrigation water applied to the land may be dissipated in three ways: A part is utilized by the plants, some is lost by evaporation from the soil, and when the quantity applied exceeds the moisture-holding capacity of the soil the excess percolates into the subsoil below the root zone. The part lost by evaporation from the soil leaves all of its dissolved salts behind. The quantity of the common alkali salts absorbed by the

plants themselves is negligible. It is only the water that percolates downward through the root zone that carries salt away.

When the system of irrigation is such that the water applied is all dissipated by plant absorption and by evaporation, practically all of the salts brought in by the irrigation water are deposited in the root zone. Even when the salt content of irrigation water is low this accumulation goes on, and it is merely a question of time until it reaches harmful proportions.

Thus it is clear that in the practice of irrigation it is vital for the continued productivity of the land that the root zone should be leached periodically, or, in other words, that some part of the water applied pass downward through the soil, for it is only in this way that the excessive accumulation of salt may be avoided. The only time that it is practicable to do this leaching is before the crop is planted.

The probable explanation of the fact that the productivity of the land under irrigation in the Salt River Valley has not been more generally impaired is that a certain amount of leaching has been practiced unconsciously. The behavior of cotton on different soil types gives ground for this belief. It has long been recognized that as a rule cotton does best on soils of rather coarse texture which take water readily. Why this is so has not been generally understood, but probably a very important contributing cause has been the use of water in such quantities that penetration to a depth well below the root zone often occurs, and the operator has kept the salt content low by unconscious but none the less effective leaching. It should be recognized that some of the irrigation water has a relatively low salt content and that the accumulation of salts in the root zone is a slow process. Under such conditions many years may elapse before the salt content of the soil solution reaches proportions injurious to plant growth. The higher the quantity of salt carried in the irrigation water the sooner the productivity of the soil will be impaired unless sound irrigation practices are adopted.

Some of the water used for irrigation in the Salt River Valley contains salts to the amount of 600 parts per million, and at times water containing as much as 1,500 parts per million is used. The amount of water required to produce crops in the Salt River Valley is variable, but it is not at all unusual to apply 4 acre-feet per acre each year. An acre-foot of water weighs 2,720,000 pounds; consequently, if the water contains 600 parts per million of salts, each acre-foot of water would deposit in the soil 1,632 pounds of salt; and if the annual use were 4 acre-feet, the total yearly deposit would be at the rate of 6,528 pounds, or 3.26 tons. In the event the water contains 1,500 parts per million, each acre-foot would carry 4,080 pounds of soluble salts; and in case 4 acre-feet were used, the annual contribution of salts would be 16,320 pounds, or 8.16 tons per acre.

Soils with a salt content much in excess of 0.5 per cent are generally considered approaching the danger point. Assuming that an acre of soil 1 foot deep weighs 4,000,000 pounds, 0.5 per cent of salt is equivalent to 10 tons per acre-foot of soil. Granting that the cotton roots extend to a depth of 6 feet, when the salt content has reached the dangerous proportion of 0.5 per cent to the full depth of 6 feet there would be 60 tons of salt per acre in the root zone. Even the unirrigated desert soils normally have a salt content ranging from 0.05 to 0.1 per cent, an average roughly of 1.5 tons per

acre-foot of depth, or a total for the 6 feet of 9 tons. It should be kept in mind that some of the salts carried in solution in irrigation water have a low degree of solubility; that is, some of the salt is precipitated from the soil solution while the concentration is still well below the danger point for plants. In general, where an irrigation water contains not more than 600 parts per million, it may be assumed that half this quantity is of low solubility and only the other half would remain in the soil solution. But with waters containing 1,500 parts per million of salts, two-thirds may be of high solubility.

Thus the yearly deposit of salts in the root zone, assumed to be 6 feet in depth, in the case of the stream containing 600 parts per million, would be at the rate of approximately 1.63 tons a year. Deducting the 9 tons assumed to be in the soil in its natural state from the 60 tons estimated as harmful, in 31 years the accumulation of salts would reach harmful proportions if no measures were adopted for effective leaching. In the case of water containing 1,500 parts per million of salt of which two-thirds is highly soluble, the length of time required would be less than 10 years.

The foregoing computations are based on the assumption that the salts in the soil solution are fairly uniformly distributed to the full depth of 6 feet. If the method of irrigation is such that less penetration is obtained, and if the amount of water applied is such that it is removed only by evaporation and transpiration, the time required to accumulate a harmful quantity of salts will be reduced proportionately. It has been observed that owing to the methods of irrigation, different concentrations of salt may occur at different depths. As a result, absorption by the roots may be so limited that, during periods of high transpiration, the needs of the plant are not adequately met. If there is an excessive concentration in a particular soil layer, susceptible crops such as cotton may suffer before the average salt content for the full depth of the root zone has become dangerously high. This probably accounts for the spotted condition of many cotton fields where, owing to improper leveling or other causes, irrigation water is unevenly applied. Many growers have experienced trouble in avoiding harmful wilting of the plants in certain areas, no matter how often water is applied. It is probable that in such cases harmful quantities of salt have accumulated in a limited portion of the root zone, due to inadequate penetration of the irrigation water, while the plants behave normally where penetration was more complete.

It would seem wise for those who are interested in the continued success of irrigation projects not only to give careful consideration to the character of the irrigation waters used but also to ascertain whether there is an accumulation of salts in the soil solution sufficient to impair productivity. It is well known that serious financial losses on irrigation projects are occurring because part of the lands are totally unproductive. The economic waste due to the losses suffered by farmers because of the impaired productivity of their land also should be a direct concern of all who are interested in the continued success of crop production under irrigation.

In order to avert the danger of harmful accumulations of salts in the root zone of his crops, the irrigation farmer must have some knowledge of the water relations of the soil. The soil of the root

zone serves as a reservoir in which to store water for the use of the plants. The effective capacity of this reservoir is limited on the one hand by the quantity of water it can hold against the force of gravity and on the other hand by the quantity of water it withholds from absorption by plant roots. The difference between these two limits in a soil is called the capacity for available water. The actual quantities of water held by the soil at these two limits are determined by its physical character, both limits being high in clay soils and low in sandy soils. But the capacity for available water differs much less in different soil types than is generally believed. In other words, the capacity for available water is only slightly less in a sandy soil than in a clay soil, though the field-carrying capacity of the former may be very much lower than that of the latter.

The weight relations of soil and of water are such that a moisture content of 6 per cent is equivalent to approximately 1 inch of water per foot of soil. Thus if 4 inches of water is applied to the surface of the soil, it will increase the moisture content by an average of 6 per cent to the depth of 4 feet. But if the surface soil is very dry, as it often is at the time of irrigation, the surface foot may hold against gravity as much as 2 or $2\frac{1}{2}$ inches of water, increasing its moisture content by 12 to 15 per cent, and in consequence there may be little or no increase in the moisture content of the third or fourth foot following a 4-inch irrigation. In a general way it may be assumed that when the soil of a cotton field is dry enough to need irrigating the soil will absorb and hold about 2 inches of water in the first foot and about 1 inch in each succeeding foot of the root zone. This explains the impracticability of attempting to leach the root zone during the season of active plant growth.

In field experiments with a sandy-loam soil it has been found that when all of the available supply of water has been absorbed by a crop of alfalfa, for example, 10 inches of water could be applied without an appreciable loss below 6 feet (9). It is not considered good practice in growing cotton to allow the soil to become so dry, but it is evident that on a sandy-loam soil an application of from 4 to 6 inches may not result in any appreciable loss of water below the 6-foot depth. It is not customary for irrigators in the Salt River Valley to apply water in such large quantities as even 6 acre-inches per application, particularly on the more impermeable soil types which occupy large areas in that valley.

From the foregoing it is apparent that where water containing substantial quantities of salt is used for the irrigation of cotton, the system of irrigation and the quantity of water applied should be designed with the view of maintaining an optimum supply of water in the root zone during the season of plant growth and of applying enough water during the winter or early spring to leach the root zone and remove the excess salt accumulated there during the previous irrigation season. When the salt content of the irrigation water is not very high it may not be necessary to leach the root zone frequently, but where the salt content is high the leaching should be done every year or at least in alternate years if accumulation of injurious amounts of salt is to be prevented.

The best time to leach the soil is in the winter or early spring between crop seasons. At this period of the year the weather is cooler and the loss of water by surface evaporation is less than at any other

time. Injury of the plants is avoided by giving the land a heavy irrigation while it is fallow. If the leaching process is to be effective, the water must pass well below the root zone; and to accomplish this in certain fields it may be necessary to provide temporary levees or borders to hold the water on the land long enough to secure proper penetration. (Fig. 6.) This is usually impracticable on land where there is a growing crop.

IRRIGATION REQUIREMENTS

To obtain a clear conception of the irrigation requirements of cotton, it will be advisable not only to discuss present practices, but also to review briefly developments that have taken place over a period of years.

Cotton production in the Southwest was as a rule recognized as a successful enterprise during the early years, and profitable yields



FIGURE 6.—Basin-irrigating land to be planted to cotton. Often it will be found necessary to adopt this method of applying water on certain soil types in order to secure adequate penetration so that harmful quantities of salts may be removed from the root zone of the plants. (Photographed by H. F. Loomis)

were obtained even when many growers were inexperienced in the growing of the crop under the conditions of irrigation. The subject of good irrigation practices was then given but little consideration by extension workers and investigators, as it was not apparent that there were serious production problems confronting the growers. It appeared then and has since been demonstrated that the requirements for proper irrigation of the crop were simple and few. Growers as a rule understood the importance of a suitable grade or slope, well-leveled land, and the application of the water in such a way that adequate and uniform penetration would occur. They did not often permit the soil moisture to be depleted to the extent that the plant growth was severely checked.

In spite of these earlier experiences, many cotton growers have come to believe that in order to secure large yields of lint it is necessary to modify materially the generally accepted methods of the application of water during the growing season. There is no evidence to

substantiate this belief. This has been repeatedly demonstrated by the high yields obtained by many farmers who have not grown cotton before and even have been inexperienced in growing crops under irrigation. It is evident that in the past too much stress has been placed on what may be designated as the superficial features of irrigating cotton as well as other crops, and too little consideration has been given to what may be called the fundamentals of sound irrigation practices and soil management. This is corroborated by observations as well as investigations.

Martin and Loomis (8) found in investigations conducted at the United States Field Station at Sacaton, Ariz., that within reasonable limits the quantity of water applied or the frequencies of application after the plants had reached the fruiting stage did not cause any consistent differences in the amount of shedding or in the yields. Such differences in yields as did occur were attributed largely to variation in the soil conditions rather than to irrigation treatments.

These results are in keeping with those published by King and others (5, 6), who found that when normal, medium heavy, and heavy applications of water were given during the growing season there were only slight differences in the yields.

Since this is true, the possibility of increasing yields by special treatment of the soil must also be considered. Cotton growers generally recognize that the plants behave normally when temperatures are moderate during the spring and early summer. Even where the plants have shed severely and abnormalities of plant growth are apparent during the hot summer months, a top crop frequently is set when the weather becomes cooler. Experienced growers have observed also that even during midsummer, if several days of moderate temperatures occur, shedding is much less severe and often of little importance. Were soil productivity the primary factor in yield, temperature changes probably would not be a material factor in causing or preventing these unfavorable plant reactions. Direct evidence is also available that yield is not wholly determined by soil fertility.

Results from a number of investigations conducted from 1920 to 1928 for the purpose of ascertaining to what extent correctives could be added to the soil in the form of commercial fertilizers were largely negative. Such beneficial results as were indicated were confined almost exclusively to soils of open texture which take water readily (10).

It would seem that these unfavorable plant reactions are not induced by lack of soil fertility, but rather by conditions of water stress. They appear to be due either to the inadequacy of the water supply in the soil, generally caused by too limited penetration, or to its lack of availability to the plants when needed at critical periods. Inadequate penetration has not only been a factor of importance in connection with the immediate water requirements of the crop, but also if continued over a period of years it may result in an accumulation of harmful quantities of salts in the soil occupied by the roots. It is well known that if the water stored in the soil contains too much salt the absorbing capacity of plant roots is reduced, and the higher the salt content the more root absorption is diminished. The results are the same as if the soil were kept too dry. Therefore, it is essential not only that there should be a quantity of moisture maintained

in the soil sufficient to meet the demands of the plants but also that the character of the water be such that it is readily absorbed by the roots in order that the transpiration losses are not greater than water absorption. It is probable, therefore, that the direct and indirect effects of insufficient penetration are mainly responsible for the condition of water stress, which in turn contributes to severe shedding and abnormalities of plant growth.

It appears necessary for the continued prosperity of the cotton industry as well as for the future success of crop production in the Salt River Valley that there be a better understanding of these fundamental principles of irrigation, to the end that growers are not led to focus their attention on factors which are probably of only minor importance in relation to the unfavorable conditions now existing on many farms. If irrigation practices in the past have been such that harmful quantities of salts have been permitted to accumulate in the root zone, or if the cropping program has been of a nature that the texture and productivity of the soil has been impaired, corrective measures attempted in the form of modifying the methods of applying water during the growing season are destined to be a disappointment.

TIME OF PLANTING

Securing a good stand of cotton is a problem confronting growers each year, and irrigation is an important factor in that problem. The young cotton plant is very susceptible to adverse conditions. Unseasonably low temperatures, rains that form a surface crust on the soil, and drying winds are all factors outside the control of the grower and operating at times to his disadvantage. For Pima cotton particularly, early planting is essential to large yields, and the coldness of the soil in early spring often retards germination. Good results can not be expected even under favorable weather conditions if the seed bed is not properly prepared, but usually are obtained even with early planting if the seed bed has been thoroughly prepared, the land well irrigated, and the planting properly done (3).

Many successful growers plant as soon after March 1 as weather conditions permit. Numerous advantages result from early planting. While the young cotton plants are developing, cool weather restricts their vegetative growth and encourages the development of a type of plant adapted to early, heavy, and prolonged fruiting. If cotton is planted late on fertile soils it is often difficult to avoid excessive vegetative growth, but experienced growers recognize that the dangers of such growth are greatly reduced if the plants are fruiting heavily when the period of high temperatures begins. Consequently, early planting not only offers distinct advantages in yield but it simplifies materially the irrigation problem. Although probability of too vigorous growth during cool weather is very remote, if the crop is overirrigated, as warm weather appears, too rapid growth will often occur at the expense of early fruiting.

Relatively close spacing of cotton plants affords one method of controlling undesirable vegetative growth, which at times occurs at the expense of fruit. Under average conditions both Pima and upland cotton are thinned to single plants space from 12 to 15 inches

apart. At times reasonably delayed thinning may also be helpful as an aid to the development of a type of plants most likely to produce large yields (2).

LAND PREPARATION AND METHODS OF WATER APPLICATION

The aim of irrigation is not only to supply the growing cotton plant with sufficient soil moisture to a depth that is conducive to the development of an adequate root system but to maintain moisture conditions throughout the fruiting season so that normal growth may continue and injury from stress conditions due to an inadequate moisture supply may be avoided. The extent of injury to the cotton crop during very hot weather is materially reduced if the root zone is thoroughly and uniformly moistened at each irrigation. Hence proper preparation of the land and the most effective method of applying water throughout the growing season are of fundamental importance. Regardless of the method of water application, it is essential that the land be well leveled. The expense of properly doing this is amply repaid by increased yields, economy in labor, and the improved quality of the lint.

The slope or grade to be given the land will be determined by the method to be used in applying the water and by the character of the soil. If basin irrigated, obviously the land must be level in all directions. The more open the soil the greater may be the grade where either the furrow or the border system is used. Under either system a slope of about 6 to 8 feet to the mile is considered satisfactory under average soil conditions. On fine-textured soils a slope of less than 6 feet to the mile is often desirable in order to secure proper penetration, and often on such soils the basin method may be used advantageously. If the slope adopted is not suited to existing conditions it will be a source of annoyance and waste of both labor and water throughout the irrigation season and of disappointment when the crop is harvested.

In the event that the land has been under cultivation for some time and has previously been well leveled, it usually requires but little preliminary treatment each season aside from "floating" with a rectangular drag 6 or 8 feet wide and 10 or 12 feet long, the size and weight depending upon the motive power available on the farm. This tool eliminates irregularities incident to caring for the previous crop and plowing preparatory to the first irrigation.

No one system of irrigation can be expected to prove equally satisfactory for all fields in an area covering as wide a range of soil types and topographical features as are found in the Salt River Valley. The method adopted should permit uniform and thorough irrigation at a reasonable expense.

DRY PLANTING

When dry planting is practiced the land is plowed, disked, and harrowed to prepare a proper seed bed. The seed is planted on or near the surface of the dry ground and then covered to a depth of 4 or 5 inches by means of disks attached to a cultivator. The field is then irrigated, the water usually flowing between the rows. After the ground has dried out sufficiently the field is drag harrowed, usu-

ally at right angles to the rows, and the ridges are leveled so that the seed is covered to a depth of about 2 inches. Such fields usually are furrow irrigated thereafter. Some growers object to this system because too often a poor stand results from the seed being covered unevenly. Often, too, the amount of water applied is so limited that an irrigation soon after the plants appear is necessary. This adds to the expense of growing the crop, and, furthermore, irrigating when the plants are small and weak and the nights cool should be avoided whenever possible.

THE BORDER METHOD OF IRRIGATION

The border system of irrigating cotton is largely practiced in the Salt River Valley at present. It consists in dividing the field into strips by parallel levees thrown up with a disk or other suitable implement in the direction the water is to flow and of sufficient height to retain the water. The distance between the levees varies. On land with but little if any side fall they are often spaced 4 rods (66 feet) apart, although the customary and more practical distance is usually close to 2 rods, or 33 feet. If the side fall is excessive, the distances between the levees are sometimes reduced to less than 33 feet. In laying out borders, the slope of the land must, of course, be considered. Where this system is adopted it is essential that the slope be uniform and that the land at right angles to the borders be level if a uniform application of water is to result. Obviously such distribution would be facilitated by proper initial leveling, but often the cost is believed to be prohibitive and frequently would necessitate, in addition, permanent borders. Most farmers who grow cotton and alfalfa in rotation do not consider permanent borders practical, as it is often found that for cotton a grade of 8 feet or less to the mile is the most satisfactory, whereas for alfalfa a steeper slope may be desirable in order to get the water over properly without too great a loss by seepage, particularly on soil types that take water readily.

An objection to the border method of irrigation is the difficulty of obtaining a uniform application of water which is essential to securing a good stand of cotton. The border method usually requires relatively large heads of water. If the land slopes steeply in the direction in which the water flows, temporary cross checks between the borders are necessary to retard the flow, uniformly distribute the water, and prevent soil erosion. (Figs. 7 and 8.)

The levees or checks between the borders are objectionable. Making them in the spring before planting causes expense, particularly when large ones are required, because of a heavy side fall. They are troublesome in plowing after the cotton crop is removed. It is not easy to keep them free from weeds, since it is difficult properly to cultivate the rows next to them, particularly when the cotton is young. The stand of cotton in the rows on either side of the levees is often poor, owing to the difficulty of planting.

THE BEDDING OR LISTING METHOD OF IRRIGATION

Under the bedding or listing method the land is usually prepared with a lister or double moldboard plow, the furrows being made about 10 inches in depth and about 42 inches apart, or the same distance as

the cotton rows. Preparatory to planting the field, the irrigation water is run down the furrows long enough to wet the ridges thoroughly, and, when the soil has become sufficiently dry to cultivate,

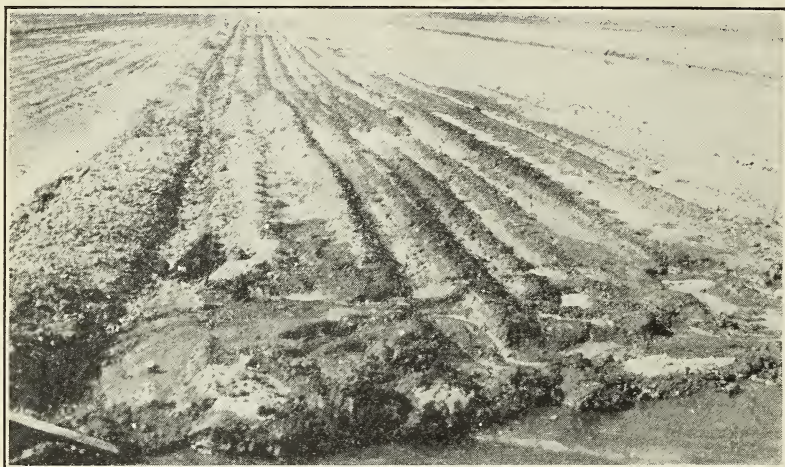


FIGURE 7.—Border systems of irrigation on land with a definite side slope, showing water ponding on the right and dry soil at the left. An uneven application is inevitable under such conditions

the ridges are leveled by a float or drag harrow, and the cotton is planted on top of them. This method was extensively practiced during the early years of cotton growing in the valley, but it has been



FIGURE 8.—A field just irrigated by the border method, showing erosion and checks thrown up to distribute the water. This condition is too often noticeable where this system of irrigation is practiced on land where the slope is too great and the land is not properly graded between the levees

largely abandoned, as poor stands frequently result from the unequal wetting of the ridges. This condition has been particularly noticeable where the soil is heavy and water penetration is slow. Planting

in the bottoms of the furrows between the ridges is a variation of this method, but it is not commonly used, because difficulty is often experienced in cultivating the land without injury to the small plants. The chief advantage of the bedding or listing method is that it can be used in fields that have not been well leveled. It should not be assumed that this method is a satisfactory substitute for proper leveling of the land, because it is seldom possible to apply irrigation water uniformly on poorly leveled land even with deep lister furrows.

BASIN IRRIGATION

At the present time the basin method of applying water to cotton fields is but rarely practiced in the Salt River Valley. The expense involved in completely leveling the land is usually greater than for the other systems described. However, the advantages of basin irrigation on some soil types and under certain conditions should not be ignored. Proper penetration of water in the heavy soils of the valley is often difficult to obtain and frequently not accomplished unless given special attention. If such a condition exists the grower may be forced to apply water in basins if the needs of the growing plants are to be adequately supplied. In other instances the construction of basins may be found necessary in order to apply enough water to insure effective leaching and the removal of harmful salts from the root zone. (Fig. 6.)

FURROW IRRIGATION

Each of the foregoing methods of applying water has merit under certain conditions, but each has also one or more features that are at times objectionable. The furrow system of irrigating cotton has been in use, to a limited extent, for several years in the Salt River Valley, but its advantages have not been fully recognized. It is believed that more general use of this system would result not only in greater economy in the use of water but also in larger yields of lint having an improved quality.

Under the furrow method the land is plowed, disked, drag harrowed, and, if necessary, floated, so that the slope may be uniform. The land is then furrowed with 8 or 10 inch furrow openers. The furrows may be made with an ordinary cotton or orchard cultivator, but the attachment shown in Figure 9, specially designed to be used in connection with a tractor, has proved to be more satisfactory than any others tested, owing to its weight and rigidity. In irrigating preparatory to planting, it is advantageous to space the furrows about 22 inches apart, which insures a more thorough and uniform wetting of the soil than is possible when they are farther apart.

Where only an earth-bank service ditch is available it may be advisable to construct a smaller one parallel and close to this ditch with frequent checks from which small streams of water are turned directly into the furrows. Wooden outlet boxes about 2 by 2 inches may be placed in this supplementary service ditch. These simplify the distribution of the water and, while desirable, are not essential, as numerous tests have demonstrated that the water may be distributed quite satisfactorily without them.

Small streams of water are turned down the furrows, the size of the streams depending upon the character of the soil and the length of

run. Obviously care must be exercised in controlling these streams, in order to avoid cross breaks; and the success of the method further depends upon proper leveling of the land to a uniform slope. It will



FIGURE 9.—A tractor attachment for furrowing, to irrigate young cotton in a field that has no borders. This tool can be used satisfactorily in furrowing the land for irrigation preparatory to planting

be found that within reasonable limits any desired quantity of water may be applied, depending upon the length of time the water is allowed to run in the furrows. (Fig. 10.)



FIGURE 10.—Irrigating young cotton under the furrow system. The side fall is approximately 18 feet to the mile, and yet no difficulty was experienced in controlling the water. Note the absence of borders and the uniform distribution of the water

After the land has been irrigated and has dried sufficiently, the seed bed is disked and drag harrowed and planting done in the same way as under the other methods of irrigation. A much more uniform

application of water will result, and the land can be prepared for planting sooner after furrow irrigation than is possible after flooding.

For the irrigations after planting, furrows are opened between the rows in the manner described above. (Fig. 11.) Since it is customary to set the shovels so as to throw the earth toward the cotton plants as they become larger, by the time the cotton is "laid by" the furrows are of sufficient depth and permanency to permit the irrigation to be continued throughout the remainder of the season without further special preparation.

Furrows similar to those described above are valuable when, under any system of irrigation, the surface soil around the seed dries out before germination, because of high winds or other reasons. This frequently happens even under the most favorable conditions for application of water, preparation of land, and planting. When it does occur, the furrows may be made and an irrigation given which will moisten the soil about the seed without flooding the entire sur-



FIGURE 11.—Young cotton recently irrigated by the furrow method. Note the apparent uniformity of application. Harmful compacting of the soil surrounding the young, tender plants is avoided by confining the water to the furrows

face. (Fig. 11.) If this is properly done good germination usually will follow. Flood irrigation of cotton fields for the purpose of germinating the seeds is rarely successful.

Another advantage of the furrow system is that it permits the use of small heads of water as effectively as larger ones, thus avoiding excessive waste. Not only will there be a more even distribution of water than where the border system is used, but also a material saving in the quantity necessary to moisten the field, and a saving in the number of irrigations required.

One of the chief reasons why the furrow method of irrigation has not been more generally used appears to be the unfounded belief that it is not practicable where only earth-banked service ditches are available or where there is much side fall in the land. While it is true that the handling of the water is greatly simplified by pipe lines or concrete ditches, yet there are no serious disadvantages in the furrow method where only earth ditches are available. Care must

be exercised that approximately the right quantity of water is turned down each furrow. If too much is used, particularly on land with considerable side fall, severe washing and waste are inevitable. Observations made in recent seasons on large-scale cotton production in the Salt River Valley show that the furrow system is satisfactory under a wide range of soil and topographic conditions.

In weighing the merits of the different systems of applying water herein described it should be recognized that no one system of irrigation can be expected to prove equally satisfactory for all fields in an area covering as wide a range of soil type and topographical features as are found in the Salt River Valley. The method adopted should be one that will permit uniform and thorough irrigation at a reasonable expense. Under skillful management on well-prepared land, good results may be obtained with any of the several methods. However, under a given set of conditions some one method usually proves to be more satisfactory than others.

IRRIGATION PREPARATORY TO PLANTING

The first irrigation preparatory to planting is in itself as important as any of the later applications. Contrary to the somewhat general belief, irrigation water applied at this time serves a useful purpose in addition to moistening the soil so that the seed will germinate readily. The application of water to young, tender cotton plants when the weather is cool retards their normal, healthy development and is recognized as an undesirable practice if the best results are to be obtained. Hence experienced growers apply the first irrigation with a view not only of providing soil moisture conditions favorable to seed germination but also for the purpose of wetting the first 5 or 6 feet of soil so completely that the needs of the plants will be adequately supplied for as long an interval as possible before the next irrigation becomes necessary. Some growers find it to their advantage to irrigate twice before planting, a procedure often to be recommended, particularly if the first irrigation does not uniformly and completely penetrate the soil to the proper depth.

The amount of water necessary to wet the soil thoroughly and to the proper depth is often underestimated. Following winters of light precipitation, if no water has been applied to the land during the preceding months, the percentage of moisture in the soil is often low; and under such conditions the amount required to wet it completely to the desired depth is often greatly in excess of that required following frequent applications. Experienced irrigators have found that the first spring irrigation may require approximately double the amount of water necessary to apply thereafter to obtain the same depth of penetration. The use of a soil auger is one of the most effective methods of ascertaining whether the soil has been wet to the desired depth, although a fair estimate may be made by computing the number of acre-inches applied. Under average soil conditions an application of 6 acre-inches is not excessive, and if the soil is dry and of a relatively fine texture more than 6 inches may be required.

The recent appearance of the pink bollworm in the Salt River Valley may prove to be a limiting factor of importance in connection with cotton production. If such a condition develops, the

most effective control measures should be adopted. Among the ones recommended are those related to plowing and irrigation. Recent investigations conducted at Presidio, Tex., by the Bureau of Entomology and Agricultural Engineering of the United States Department of Agriculture (4) have indicated that 6-inch plowing with a moldboard plow, followed immediately by an irrigation of at least 7 inches, is effective in decreasing larval survival. Thus a relatively heavy preplanting irrigation, which wets the soil to a depth likely to be occupied by the roots of the plants, will be a desirable practice to follow in general, and it also offers distinct possibilities in connection with pink-bollworm control.

PREFRUITING IRRIGATION

The first irrigation after planting should be delayed as long as possible. This does not mean that the plants should be stunted so that fruiting is delayed, but rather that vegetative growth should be restricted sufficiently to promote early fruiting. Temporary wilting in the middle of the day, particularly when temperatures are high, does not necessarily indicate that an irrigation is required. However, if wilting occurs early in the forenoon the field should be irrigated.

Contrary to the somewhat general belief, so-called light applications of water are seldom to be recommended, and particularly not during the prefruiting period of the cotton plant. With the system of irrigation now generally in use in the Salt River Valley it is seldom possible evenly to distribute a very light irrigation. As a result, in some areas the penetration of water is limited, while in other parts of the same field or border the soil is thoroughly saturated. This causes uneven growth and intensifies the difficulties later encountered when those parts of the field that receive but little water will need another irrigation while other areas may not. Completely wetting the soil of the entire field to the full depth of the root zone prior to planting and then postponing the next irrigation as long as possible gives the most satisfying results.

However, while the plants are still small there may be periods of dry and windy weather when the moisture in the surface soil is dissipated to such a low point that there is danger of injury to the tender, young plants, even though there may be an ample supply of water in the lower soil. In that event a light irrigation may be given with no harmful effects, but flooding the field at this time should be avoided. A better practice is to furrow irrigate, as shown in Figures 10 and 11, thus avoiding wetting the soil around the tender plants.

When irrigation before planting has been inadequate and the crop is watered while the plants are small and the weather is still cool, particularly if the field is flooded, there is often a temporary checking of growth and serious injury to the plants from "sore shin," a disease caused by a fungus (*Rhizoctonia*).

MIDSEASON IRRIGATION

When the cotton plants begin to fruit the program of irrigation should be altered to provide them with an adequate and continuous but not excessive supply of water. On soils of the more open types,

particularly those lacking in humus, there is little danger of over-irrigation. On the heavier and more productive soils which have recently been in alfalfa there may be some danger of overstimulation, particularly during the early part of the fruiting period. Best results are to be expected by so arranging the irrigation schedule that a continuous growth of the plants occurs. The soil should not be allowed to become too dry, and, on the other hand, irrigations should not be so frequent that abnormal vegetative growth results at the expense of fruit.

The best indication of when to irrigate during the fruiting period is given by the plants themselves. The wise cotton irrigator does not adopt an arbitrary schedule in advance nor attempt to judge the need of irrigation wholly by weather conditions or the apparent moisture content of the soil. When the cotton plant has begun to produce buds and flowers, the fruiting branches and the main stem begin to compete for the water supply. When the supply is ample for both, the apical growth keeps ahead of the fruiting branches. As the water supply diminishes, the growth of the main stem is retarded more than that of the fruiting branches. The effect of this competition may be observed from day to day. If, in looking across a fruiting cotton field, a few flowers are readily observed among the top leaves and buds, this is evidence that the water supply is adequate. The proper position of the squares and flowers in relation to the top of the plants is that in which the squares are readily discernible and a few flowers are noticeable in looking over the field. When only the leaves are apparent a too-rapid growth is being made. The flower-garden effect, on the other hand, indicates too restricted a growth and a need of irrigation. As the season advances and the plants become large and more heavily loaded with bolls, the water requirements are higher, and indications of need of water should be carefully watched. To permit the plants to suffer even for a few days may not only reduce the yield but may injure the quality of the lint in the bolls already partly matured.

The plant conditions described in the preceding paragraph are more readily discernible in Pima cotton than in the upland types. In upland cottons the relative position of the flowers is less conspicuous, but striking and significant changes occur in the color of the foliage. As the supply of available water becomes depleted the leaves of the upland plants become darker colored with a distinctly bluish tinge, and definite wilting is apparent. This condition appears first in the drier spots of the field and should not be permitted to continue, or injury to the crop will result. With upland cotton as with Pima, a prolonged period of active vegetative growth during the fruiting period should be avoided, yet too severe restriction of growth by withholding water during that period may aggravate the losses through shedding of buds or bolls. Plants of both types are subject to such losses, but upland cottons are more susceptible.

Stirring the surface soil after an irrigation materially aids the penetration of the water. Since cultivation ordinarily ends early in the fruiting season and this effect is not obtained after the later irrigations of the plants, the later irrigations demand special care in order that the root zones may be completely moistened. This often involves the use of smaller irrigation heads, permitting the water to remain in the furrows or on the border for a longer time,

LATE IRRIGATION

Normally, bolls of Pima cotton set after September 15, and bolls of upland varieties which set after the latter part of the same month do not open before the first killing frost. Consequently, the middle of September for Pima and the latter part of the month for upland may be considered the dividing line between midseason and late-season irrigation. The irrigation schedule should be so arranged for the late season that the soil moisture is adequate at all times to meet plant requirements. Permitting the soil moisture to reach such a low point that the needs of the plant are not supplied at this time may impair the yield and quality of the lint as seriously as will the same condition occurring during midseason.

The water requirements of the plants are somewhat lower at this season than during the fruiting or midseason period, the temperatures are lower, and transpiration is less. The intervals between irrigations may be extended as the weather becomes cooler, but it is not advisable to try to use less water at each irrigation.

Contrary to the belief sometimes expressed, it has not been demonstrated that irrigation during the period of late ripening materially retards normal maturity and opening of the bolls. On the other hand, there is abundant evidence that if the soil is not supplied with sufficient moisture for the needs of the plants, the bolls may open prematurely and the quality of the fiber be seriously impaired.

FREQUENCY OF IRRIGATIONS AND SEASONAL WATER REQUIREMENTS

Under such a wide range of soil conditions as are found in the Salt River Valley, it is obvious that only the most general statements can be made regarding frequency of irrigations or quantity of water required to produce a crop of cotton. The land should be irrigated before planting even if there is moisture in the surface soil supplied by rains sufficient to germinate the seed. Thoroughly moistening the soil just prior to planting postpones the time when the next irrigation is required. Under favorable conditions, when cotton is planted the middle of March the first irrigation after planting may not be necessary until the middle of May or even the early part of June, but the later date is the exception rather than the rule. If planting has taken place in March, the first irrigation usually is given in the last half of April or early in May, immediately after thinning. The frequency of succeeding irrigations is governed by the rapidity of the growth of the plants, their size, and the amount of fruit on them, as well as by the rainfall, temperature, humidity conditions, the character of the soil, and the quantity of water applied at the last irrigation. Irrigations are required most frequently during the height of the fruiting season, that is, during the last half of July, August, and early September. Soils with a low humus content, recently reclaimed from the desert, have been found to require applications as often as every week or 10 days, whereas soils that have been cropped for a number of years are well supplied with humus, take water readily, have a high water-holding capacity, and may remain in a satisfactory condition for three or four weeks between irrigations and in exceptional instances for even a longer period.

Temperature conditions usually become less extreme about the middle of September, which date may be taken as the dividing point between midseason and late irrigation of the cotton crop. Thereafter the frequency of the irrigations becomes progressively less until the crop is completely matured.

The quantity of water that should be applied at each irrigation is governed by a number of factors. It has been emphasized that the soil should be moistened, if possible, to a depth of 6 feet. Otherwise the root systems of the plant are likely to remain shallow, and there will be danger of heavy shedding and impairment of the quality of the lint. Whether or not proper penetration is being secured is best determined by tests with a soil auger or a shovel.

The cotton grower should not be confused by the assumed advantages of so-called "light" irrigations where the idea is to moisten the soil only to a slight depth. The practice is to be avoided in all but very exceptional instances. It is well to recognize that under irrigated conditions the root zone of a normal cotton plant extends to a depth of at least 5 feet and often more, and in order for the roots to occupy this zone the moisture conditions must be favorable. The roots will not grow from moist into dry soil; hence, continued shallow wetting of the soil will restrict their normal and proper development.

Another danger of continued light irrigation is in the accumulation of harmful quantities of salt in the root zone. Where the concentration is near the toxic limit, even a few light irrigations may have extremely adverse effects on plant growth by so increasing the concentration in the moistened area that the plants are unable to absorb moisture sufficient for their needs, even immediately after water is applied.

Normal deep-rooted plants may be developed through proper irrigation during the early growing season, but as the season advances and the water requirements of the plants are increased, inadequate irrigations may cause serious losses due to shedding and injury to the quality of the lint. Irrigations should be most frequent during the fruiting period. At that time the quantity of water applied at each irrigation should equal if not exceed that applied at any earlier irrigation. The unsatisfactory condition of the plants often observed either in whole fields or in circumscribed spots is usually due to inadequate penetration and might have been avoided by giving more attention to this important phase of irrigation.

Many factors must be considered in estimating the total quantity of water required to produce a crop of cotton. The quantity is determined not only by temperature and rainfall but by the physical character and humus content of the soil and by the size of the plants. Other conditions being equal, the higher the summer temperatures and the longer the growing season the more water is required. Soils of medium texture which take water readily usually require less water and produce larger crops than very sandy soils or soils of fine texture in which it is difficult to obtain deep penetration of the irrigation water. Soils well supplied with humus appear to require less water than those lacking in it. The quantity of water required is also influenced by the method of application and the skill used in applying it. Under certain unusually favorable conditions a good crop of Pima cotton has been produced in the Salt

River Valley with less than 3 acre-feet of water, while in other fields as much as 5 acre-feet were required. It is evident that to produce the most satisfactory results the grower should not decide in advance how much water he will use but will be guided by the needs of the plants.

ALFALFA AS AN AID TO IRRIGATION OF COTTON

The value of alfalfa in a rotation for maintaining and improving the productivity of the soil has long been recognized, but its favorable influence on the physical condition of the soil and hence its aid to irrigation should not be ignored. In the Salt River Valley alfalfa is extensively grown, partly as a hay crop and partly for its value in rotation with cotton and other crops. During the latter part of the World War and the two years following, when cotton prices were high, the acreage of alfalfa was materially reduced, and Pima cotton was grown continuously on the same land for several years. It was apparent that this practice had an adverse effect on the yields.

This reduction in the yields, experienced by many growers, substantially contributed to the belief that more satisfactory returns could be obtained by substituting certain upland varieties for Pima. The result was that, beginning with 1923, upland cotton was extensively planted in the valley. Statistically, it is not apparent that production problems with Pima cotton had developed, because the places in which upland cotton has been substituted are chiefly the areas where yields from the Pima variety were materially less than those formerly harvested.

The acreage of alfalfa in the valley was reduced from 47 per cent in 1916 to 12 per cent in 1920, on the basis of the total acreage to which water was delivered by the Salt River Valley Water Users' Association. It is believed that this reduction in the alfalfa acreage was an important factor in lowering the yield of Pima cotton. It is recognized that alfalfa not only performs a useful service in contributing to the nitrogen supply of the soil but also modifies the physical condition of the soil so as to facilitate materially the penetration of water, particularly on the heavier soil types. Incorporating alfalfa in a rotation with cotton lessens the difficulty of securing adequate water penetration, which in turn will reduce injury caused by stress periods and by the crazy-top disorder.

CULTIVATION

Cultivation of cotton as long as the size of the plants will permit is well recognized as a desirable practice in growing cotton. Maintaining the surface soil in a loose, friable condition is a distinct help to water penetration, and the extent to which penetration is retarded when cultivation ceases and the soil "slicks" over is not always fully recognized. Cultivation is also beneficial in conserving moisture by eliminating weeds. Excessive growth of weeds is harmful to the young cotton plant because it shades them and robs them of soil moisture. After planting cotton, cultivations should be as frequent as is necessary to prevent weed growth and to maintain the surface soil in a loose, friable condition. Effective cultivation will make it

possible to postpone the first irrigation after planting. As the plants become larger the soil between the rows is gradually worked toward them at each cultivation until at the last cultivation there are well-defined furrows between the rows. These furrows facilitate distributing the water under border irrigation and are essential under the furrow method.

RELATION OF SOIL-MOISTURE CONDITIONS TO SHEDDING AND CRAZY-TOP DISORDER

Shedding some of its squares and bolls is a characteristic behavior of the cotton plant. In the irrigated valleys of the Southwest with relatively high summer temperatures shedding is often very severe, and losses sustained on this account reach serious proportions. No complete explanation of the causes of shedding appears to be available, but it is apparent that where soil conditions are favorable and proper cultural and irrigation practices are followed, shedding is reduced until good yields may be obtained even during seasons when climatic conditions are most adverse.

During certain periods in midseason it often happens that for several days no buds and young bolls are retained on the plants, and under extreme conditions excessive shedding may continue for a longer period. While the weather is relatively cool the plants usually behave normally, and little shedding is noticeable. (Fig. 2.) With higher temperatures shedding becomes more pronounced, the severity being materially influenced by the abruptness of the change. Shedding is distinctly more noticeable on heavy soils where proper penetration of water is difficult to obtain. This may be attributed to a water-stress condition of the plants. The unfavorable effect of high temperatures is aggravated by permitting the moisture content of the root zone of the soil to reach such a low point that the quantity of water available for absorption by the roots is less than that transpired by the leaves. As a result the normal development of the plant is checked, and severe shedding ensues. It has also been pointed out that stress conditions may develop even when the moisture supply in the soil is ample, if the soil solution contains an excess of salts.

Unsound irrigation practices are not only an important factor in causing shedding but appear greatly to intensify the losses sustained from crazy top. This disorder of cotton plants is now of serious economic importance, and the areas involved are increasing. Apparently the first symptom is the shedding of the squares or buds, which increases in severity until in the more advanced stages almost complete sterility and distinctly abnormal vegetative growth occur. It is highly significant that the disease is often associated with soils notably impervious to water or those where the grade is too steep to permit proper penetration. A study made by King and Loomis (?) of the root development of normal cotton plants as compared with those of plants seriously injured by crazy top has shown that where normal deep rooting occurred the plants usually were free from the disease, while the roots of plants showing marked injury seldom penetrated below a depth of 2 feet, with a shortened taproot and a shallow lateral rooting system. These investigations have shown further that the disorder occurs chiefly where proper

moisture conditions were not maintained to a depth sufficient to permit normal root development.

It is recognized that the crazy-top disorder may be caused primarily by some disease organism yet undetermined, or be due to some element in the soil solution having a toxic effect on the plant; but, whatever the cause, the injuries are greatly aggravated when the conditions of growth are unfavorable.

It is not assumed that the crazy-top disorder may be completely eliminated by adopting more efficient irrigation practices during the growing season. In examining fields where the disease has been prevalent, however, it has been apparent that at the lower ends where the water was impounded the plants were normal, but where the water penetration was shallow the plants were practically sterile and showed other symptoms of the disorder.

Thus it appears that inadequate irrigation may be an important factor in the occurrence of crazy top. Obtaining deep penetration of the water when preparing the seed bed and thoroughly wetting the lower part of the root zone during the fruiting period appear to have a marked effect in reducing the injury from this disease.

Reduction in yield is not the only loss sustained by growers when cotton is subjected to severe stresses, as it has been found that when yields are materially reduced because of adverse growth conditions the quality of the lint also is impaired. The extent of the deterioration is roughly in proportion to the severity of the adverse conditions. This variation in the quality of the lint has been recognized for some years by buyers and consumers, and has often been attributed to a decline in the quality of planting seed. However, repeated tests under carefully controlled conditions have demonstrated that seed stocks now available are fully equal to if not superior to those planted during the earlier years of cotton growing in the Salt River Valley.

The opinion has been expressed that this condition could be improved or wholly corrected by the substitution of other varieties. All the evidence obtainable indicates that similar difficulties will be encountered regardless of the variety grown as long as the growth conditions are such that the plants can not develop normally.

SUMMARY

While cotton growing is a relatively new agricultural enterprise in the Salt River Valley of southern Arizona, somewhat more than one-third of the total crop acreage in Maricopa County was devoted to the crop in 1930. The types grown are American upland and the Pima variety or American Egyptian.

Prior to 1923 the Pima variety was almost exclusively grown in the county. A few years after cotton became an important factor in the agricultural program of the valley, difficulties developed on certain soil types. As some growers believed that better results could be obtained with certain upland varieties, beginning in 1923 the cotton acreage has been planted in varying percentages to this type of cotton, with the Acala variety predominating. The expected advantages from this substitution of varieties have not been realized. Unfavorable growth conditions have reacted equally unfavorably on all plants regardless of variety.

The climate of the Salt River Valley part of Arizona is characterized by rather high summer temperatures, light rainfall, and low humidity. Changes from moderate temperatures to those materially higher often are abrupt, which greatly increase the transpiration strain.

When growth conditions are not favorable the plants (1) shed squares or bolls, (2) reduce the size of the bolls, (3) show the abnormalities of growth known as "crazy top," and (4) produce a lower quality lint. Where serious production problems have developed, slight modification of the generally accepted practices in seasonal application of water gives no indications of being a material factor in correcting the difficulties. The effect of commercial fertilizers has been investigated, without satisfactory results except on the more open soil types which take water readily.

Most irrigation water supplies now being applied in the Salt River Valley carry salts in varying percentages. Practically all of the salts thus brought in are deposited in the soil unless removed by leaching. It is essential for the continued productivity of such lands that periodical leaching be practiced.

The quantity of water that it is necessary to apply on soils with a high water-holding capacity in order to moisten the soil to a depth of 6 feet is often underestimated.

Irrigations preparatory to planting or during the winter months are the proper means for removing harmful quantities of alkali salts which may have accumulated in the soil. Uniformly moistening the soil to a depth of at least 6 feet preparatory to planting is recommended.

The securing of a good stand of cotton is largely dependent on how thoroughly the seed bed is prepared and the uniformity of the application of water preparatory to planting. Early planting is recommended, particularly for the Pima variety. Irrespective of the method of irrigation adopted, it is essential that the land be well leveled.

The methods of applying water most commonly used are: The border, bedding or listing, dry planting, basin, and furrow methods. The border method is most generally used. However, unless the land has been prepared better than is often the case and the proper slope selected, difficulties will be encountered later in uniformly applying the water. Bedding or listing is not extensively practiced. Dry planting is not recommended. Basin irrigating, while rarely practiced, often could be advantageously adopted, particularly as an aid to more effective penetration. The furrow method of applying irrigation waters has been in effect for a number of years and could be more extensively adopted to the advantage of the growers.

During the prefruiting stage cotton should not be irrigated so frequently that excessive vegetative growth is stimulated; and light irrigations where the soil is not thoroughly moistened should be avoided, or shallow rooting of the plants is encouraged.

During midseason, the period when the fruit is set on the plants, complete penetration should be attained at each irrigation. Applications should be as frequent as necessary to maintain continuous normal growth of the plants.

Bolls set after about the middle of September, for Pima, and after the latter part of the same month for upland, do not ordinarily

mature before frost. Consequently, after those dates it is necessary only sufficient moisture be maintained in the soil for the crop to be properly matured. If attempts are made to hasten maturity of the crop by allowing the soil to become too dry, the bolls may open prematurely, the yield may be reduced, and the quality of the lint may be impaired.

Alfalfa included in the rotational program with cotton aids in maintaining or improving the productivity of the soil and also improves its physical condition. Thus alfalfa materially assists in attaining more effective penetration.

Cultivation not only conserves soil moisture by keeping down weeds but is also of aid in securing better water penetration by loosening the surface soil. Cultivation should be practiced as long as the growth of the plants will permit.

Shedding of the squares and bolls and the crazy-top disorder of cotton appear to be directly associated with water stress. Injuries from these sources are intensified under inadequate water penetration or excessive salt concentration in the soil solution during periods of high temperatures.

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